TRANSLATING SNOW HYDROLOGY RESEARCH RESULTS INTO GUIDELINES FOR FOREST MANAGERS: GAPS BETWEEN THEORY AND PRACTICE

by

D. A. A. Toews and D. R. Gluns 1/

INTRODUCTION

In this paper we examine the snow hydrology-forest harvesting interface from the perspective of the forest land manager who must make decisions on timber harvesting in watersheds used for community water supply. A number of reviews of the snow hydrology - timber harvesting literature include a section on management implications. They generally do not provide sufficient guidance for forest land managers to weigh the merits of various harvesting alternatives. We examine gaps between the reported effects of forest harvesting on snow hydrology and their applicability to land management as we have experienced them in southeastern B.C. A key question is whether it is possible to derive sufficiently precise and scientifically supportable snow management guidelines to direct management or whether the "state of the art" is simply not well enough developed to undertake this task.

The issue of planning timber harvest to alter the snowpack and hence the hydrograph that is the topic of this paper is part of a larger issue dealing with scheduling timber harvest to protect watershed values as discussed by Harr (1981).

EFFECTS OF FOREST COVER REMOVAL ON SNOW ACCUMULATION AND MELT

Removal of a forest canopy typically results in greater snow accumulation and more rapid melt. A graphical representation of these principles for southeastern B.C. is shown in figure 1 where the snow accumulation and melt pattern of an adjacent forested and clearcut site on a north facing slope are compared. The important features of this graphical comparison are that the clearcut had greater snow water equivalent at peak accumulation, more rapid ablation rates during the melt season and an earlier disappearance of snow. The pattern shown on this graph has been reported in numerous other studies (Anderson 1956, Haupt 1951, Packer 1962, 1971) and although details will vary with elevation, aspect and forest cover type, its essential features remain similar for most areas.

During the past several years considerable research has been reported that relates opening size to increased snow accumulation. The work in Alberta (Golding and Swanson 1986) and Colorado (Troendle 1983) suggests that small opening sizes in the range of 2-5H (H = surrounding tree height) in diameter collect the most snow as compared to adjacent forested stands. Troendle and Leaf (1980) have published a graph that depicts maximum accumulation in a 5H diameter opening and gradually decreasing accumulation as opening size increases. Beyond 14H there is a decrease in the amount of snow when compared to adjacent forest. Work by Toews and Gluns (1986) suggests that this relationship may not be applicable to areas of southeastern B.C. We found that clearcuts were accumulating more snow than adjacent forested areas regardless of the size of the openings. The difference in accumulation and melt in forest openings becomes important in snow dominated systems as opening size and configuration are factors the manager can control.

Although we have a good knowledge of these onsite changes, we have only a general idea of how these changes are translated into streamflow. Our limited understanding comes from the studies at Fool Creek and Wagon Wheel Gap, Colorado and Hinton area, Alberta where the hydrograph was altered through forest cover removal (Troendle and Leaf 1981).

Paper presented at the Western Snow Conference, April 19-21, 1988, Kalispell, Montana.

1/ Research Hydrologist and Assistant Hydrologist respectively, Ministry of Forests and Lands, Nelson, British Columbia.

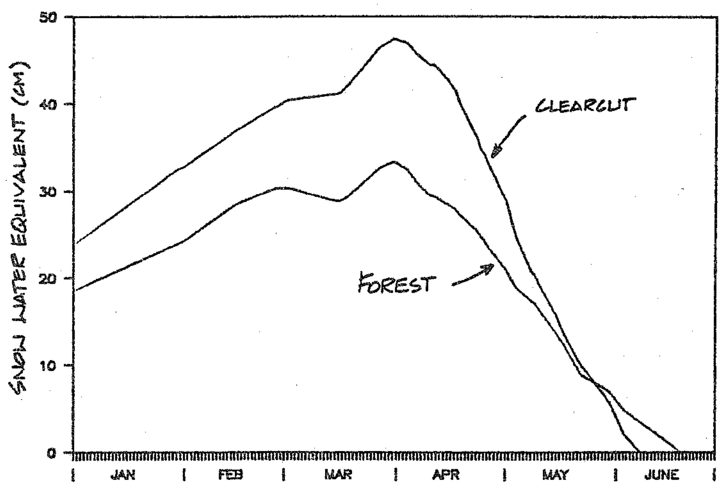

Figure 1. Average snow accumulation and ablation (1983-1987) for a north facing site at 1 375 m elevation near Rossland, B.C.

Guidelines for Timber Harvesting in the Snow Zone

Most forest management agencies in areas with watershed-timber conflicts have some form of watershed protection guidelines. In B.C. an interagency committee has published a set of guidelines dealing with land use in community watersheds (B.C. Min. of Environment 1980). Unfortunately, these guidelines lack specificity with respect to snowpack management. The U.S. Forest Service (USFS) has published procedures for Region 1 that provide some guidance with respect to snow management (USDA Forest Service n.d.). The procedures are based on the principle of desynchronizing melt on a watershed basis and hence snowmelt contribution to streamflow during critical peak flow periods. Haupt (1979) and Satterlund and Haupt (1972) also include specific suggestions for desynchronizing flows based on the alteration of the snowpack through forest management.

Most of these guidelines make qualitative suggestions for forest planning but few quantitative recommendations that can be supported by research findings. For example, the USFS Region 1 guidelines make the following suggestions. On high energy slopes the objectives are to reduce maximum accumulation, advance time of initiation of melt, and lengthen snowmelt period. To translate these objectives into management practices the USFS suggest moderate-sized openings (less than 8.1 ha) at lower elevations and openings up to 16.2 ha at higher elevations. Shading by trees to the south should be minimized. On low energy slopes, the objectives are to delay or maintain time of initiation of melt, minimize increases in water yield, reduce rate of melt and lengthen the snow melt period. These objectives are translated into practice by cutting moderate sized openings (less than 8.1 ha) on low elevation sites and creating small patches or group selection cuts at higher elevations with the intent to maximize snow accumulation and delay melt. From an operational standpoint, recommendations such as this can be problematic due to the variablity of topography, vegetation types and the logistics of timber removal. Also, these suggestions have never been verified through field studies.

Models and Watershed Analysis Methodologies

Numerous snowmelt models have been developed, each for specific areas and each requiring its own data sets. Only two methodologies are readily available for operational use by forest managers to evaluate alternate timber harvesting plans. These are the WRENSS methodology (Troendle and Leaf 1981), and the Region 1 Watershed Analysis Procedure (USDA Forest Service n.d.). These methodologies are not specifically snow management tools, but do incorporate the principles of the water balance in snow dominated systems. The two methods have modest data requirements, have been programmed for computer use, and are thus easily utilized by operational staff to assist in assessing alternative timber harvesting plans.

Both methods are designed to predict the water yield increase in a watershed attributable to a given logging plan. We have encountered problems in applying these models to operational evaluation of logging plans because the models are based on research results that do not completely reflect conditions in southern B.C. The output from these models is geared towards dealing with average yield increases which do not reflect the current concern in our area, which is scheduling timber harvest for peak flow mitigation.

DECISION MAKING CONTEXT

Forest management decisions depend upon the legislative and policy framework. This framework is worth discussing because the modelling tools that the USFS developed have arisen in response to legislative and policy requirements. In B.C. our legislation and policies are somewhat different and therefore different planning tools are necessary. Forest managers are required under Section 4(c) of the Ministry of Forests (MOF) Act to plan the use of the forest resource in cooperation with other agencies who have specific resource management responsibilities. From a forest hydrology perspective this means that the land manager must plan use of the forest resource in conjunction with agencies responsible for the management of water and fish. An important concern is the protection of streams licenced for use as a domestic and irrigation water supply. Section 4 of the MOF Act also calls for maximizing the timber resource values. A manager must weigh the economic benefits of varying levels of watershed protection. In areas with significant water and timber values decisions are made regarding how much of a watershed to harvest, what pattern that harvest should take, and what silvicultural systems should be utilized. These are decisions which will ultimately affect snow accumulation and melt patterns. We have general knowledge to use in making these decisions, but little specific quantitative information to use in evaluating the opportunity cost of watershed management.

GAPS BETWEEN THEORY AND PRACTICE

In spite of the fact that research on the effects of forest cover removal on snow accumulation and melt has been ongoing for about 75 years, managers still have difficulty trying to apply the principles to forest management. Some of the gaps are inherent in the ways that the roles of the researcher and the manager differ, some are the result of a confusion as to what the management objectives should be, and some are the result of technical gaps.

Whereas managers must evaluate land use options for a parcel of land, a researcher has a responsibility to make rigorous inferences from scientific studies. In some circumstances the research studies and associated inferences do not answer the questions the manager is asking. This may have arisen as a result of communication problems or as a result in a shift of watershed concerns.

Many watershed experiments do not coincide with current management problems. For example, many of watershed studies have primarily addressed the topic of water yield which was assumed to be the concern when the studies were initiated. Since that time other topics have also assumed importance. However since these studies have a great deal of inertia because of time scales involved, it is difficult to shift them to address new concerns.

Researchers often have not refined their conclusions sufficiently for the manager to consider the environmental merits of various harvesting options. For example a manager may be able to evaluate sufficiently the merits of a no harvesting option and of an intensive harvest but has insufficient information to evaluate intermediate options.

The key gaps between theory and practice are related to the technical topics of peak flows, water yield, and low flows. Each of these topics will be addressed by attempting to answer various questions that have arisen during discussions with timber managers.

Peak Flows

In snow dominated areas it is widely believed we can plan forest harvesting so that increases in peak flows are minimized so that channel stability is maintained, sediment transport is not excessively increased, and slopes are not destabilized. While the concept makes sense and is often applied, there has been little scientific work documenting this linkage between harvesting and peak flow increase or on the role that peak flows play in channel and hillslope response.

a) Does logging increase peak flow as a result of altering the snow accumulation and ablation pattern?

The literature suggests that peak flows can increase, decrease, or exhibit no change as a result of forest cover removal (Hetherington 1987, Troendle and Leaf 1981). For the manager, there is no tool to allow him to predict changes in peak flows that arise from various harvesting strategies. Although plot studies indicate that increased peak flows are likely following forest cover removal because of more rapid melt rates, hydrograph analysis does not necessarily demonstrate this impact.

b) Under which circumstances should managers specifically attempt to undertake snowpack management to minimize peak flows?

In the studies that report an increase, there is little comment on the significance from an impact viewpoint (i.e., Troendle and Leaf 1981). Ultimately managers must deal with the concerns of downstream users. Managers are confronted with a variety of watersheds, each with different physical characteristics. Size of watershed, topographic characeristics, slope and stream channel stability are obviously characteristics to be considered. For example, in southeastern British Columbia, in the higher precipitation areas it is evident that channel altering peak flows periodically occur. By contrast in the more topographically subdued lower precipitation areas maximum flows and their increase seem to be less of a concern. The answer to this question will probably be related to the geomorphic processes of stream channels, their frequency of peak flow occurence and the demands placed on stream by other resources.

c) Are the synchronization/desynchronization suggestions sufficiently worked out to be implemented by managers?

Satterlund and Haupt (1972) and Haupt (1979) have formulated suggestions for harvesting; the objectives are to desynchronize melt from different parts of a watershed, thereby decreasing peak flows rather than increasing them. In practice we have some problems implementing these strategies particularly where the needs of establishing a new forest override water concerns. Still to be addressed in this issue is the effect that these management strategies will have on the second and third pass of timber harvesting. If desynchronization guidelines are followed for the first pass, this would leave timber behind whose harvest would theoretically have the opposite impact. A further conceptual problem with the desynchronization argument lies in the fact that although timber removal may desynchronize flows in a parent watershed, it may also synchronize previously desynchronized flows downstream (Harr 1986).

d) Are peak flow increases and water yield increases well correlated?

These parameters are not necessarily correlated. This question is important because the major tools that are being used to predict the impacts of silvicultural treatments calculate water yield increase, yet the purpose to which they are applied is to determine if erosion rates are increased by higher flows. The major watershed studies in snow dominated areas of western Canada and the USA do not mention the topic of peak flow increase, yet the results are often used as if water yield increase and peak flow increase are synonymous.

Water Yield

Bosch and Hewlett (1982) have documented that water yield increase does occur following forest removal. However there are still uncertainties as to the processes involved. Uncertainty as to how much of the increase is attributable to snowpack changes and how much might be attributable to differential evapotranspiration after the snowpack has disappeared remains. Also, the redistribution versus interception controversy as to increased snow still exists.

In practice, water yield increase is largely irrelevant in many areas. For example, in southeastern B.C. water is relatively plentiful and it is usually more efficient for water users to look for alternate water sources rather than to gain a marginal increase using watershed management strategies. Water users most often express concern about increase in peak flows and associated channel and sediment yield changes.

Under what circumstances is it worthwhile to manage for water yield increase?

For the most part we do not consider water yield enhancement practical in our part of B.C. In a snow dominated system most of the additional yield occurs during the spring snowmelt period when water is plentiful. Very few water users have sufficient storage to take advantage of this additional yield. Water enhancement projects do become important where water is extremely valuable, there are storage facilities to capture any excess water and the project can be implemented economically.

Low Flows

The major watershed studies in the snow zone have not demonstrated any appreciable increase in flows during the spring and fall low flow period (Troendle and Leaf, 1981). There has been speculation, however that harvesting schemes that delay spring melt might enhance low flows by extending melt into the summer season.

a) Can management of the snowpack influence the flow during the summer and fall low flow period?

MacDonald (1987) has recently conducted irrigation experiments in which he simulates the delivery of melt water as might be expected from delayed melt due to a snowpack enhancement scheme. In his field studies the additional simulated yield was utilized by vegetation or infiltrated into the groundwater reservoir but was not measureable in a nearby stream channel. This study as well as the classical watershed scale studies (Troendle and Leaf 1981) suggest that enhancement of flow during the low flow period is unlikely in most snow dominated watersheds.

b) Under which hydrological and climatic circumstances will snowpack alteration due to forest harvesting tend to increase low flows?

The Streeter Basin study in southwestern Alberta demonstrates that there are exceptional circumstances where purposeful placement of openings can enhance flows in both the spring snowmelt season as well as the summer and fall low flow period (Swanson et al. 1986). Particular circumstances of the climate and hydrology of this area are the chinook winds which lead to snow disappearance in larger openings and streams whose source is small springs which are dependent on recharge during the spring snowmelt season. By creating small openings that minimized exposure to wind, the snowpack was retained to contribute to groundwater recharge and hence to flow in West Streeter Spring throughout the summer and fall. Spring fed streams whose recharge source is primarily snowmelt may offer a situation where flow enhancement is feasible.

FUTURE NEEDS AND STRATEGIES

Many of the questions that managers are asking do not have simple answers. Such issues as optimal and maximum size of opening, maximum extent of harvest in a watershed, and exact "greenup" period need a careful definition of the hypotheses to be tested and probably still are largely unanswerable. Yet these questions do not go away and continue to receive attention. Several suggestions for possible courses of action follow.

In the first place there is a need for more study on watersheds of a size with which managers are confronted. Harr (1981) called for such study after reviewing the harvest scheduling issue. In the area of B.C. in which we are working we have found a surprising amount of hydrometric data available in certain areas. For example, we have hydrometric data available on Duck Creek, a 57 km^2 watershed for the period 1947-1951, 1953 and for the period 1980-1986. In the earlier period approximately 67% of this watershed had a relatively open canopy, largely as a result of recent wildfires. In the intervening 17 years approximately 30% of the watersheds had developed a canopy. In figure 2 a monthly flow comparison between the early period and the recent period is compared. The comparison suffers from not having a control that was unchanged during the intervening period. Nevertheless the decreasing flows with canopy growth are consistent with what might be expected from examining the Fool Creek studies and the (Troendle and Leaf 1981) and the Hinton study (Swanson and Hillman 1977). These hydrographs provide at least some documentation of principles demonstrated in other geographical areas and on watersheds of a size that managers are typically dealing with.

Secondly, some new modelling tools are necessary. The two models in common use, WRENSS and the R-1 Water Yield Increase Model, simply do not address the concepts of the synchronization/desynchronization effects of alternate harvesting strategies. Satterlund and Haupt (1972) felt such a model was feasible yet to our knowledge has not been developed.

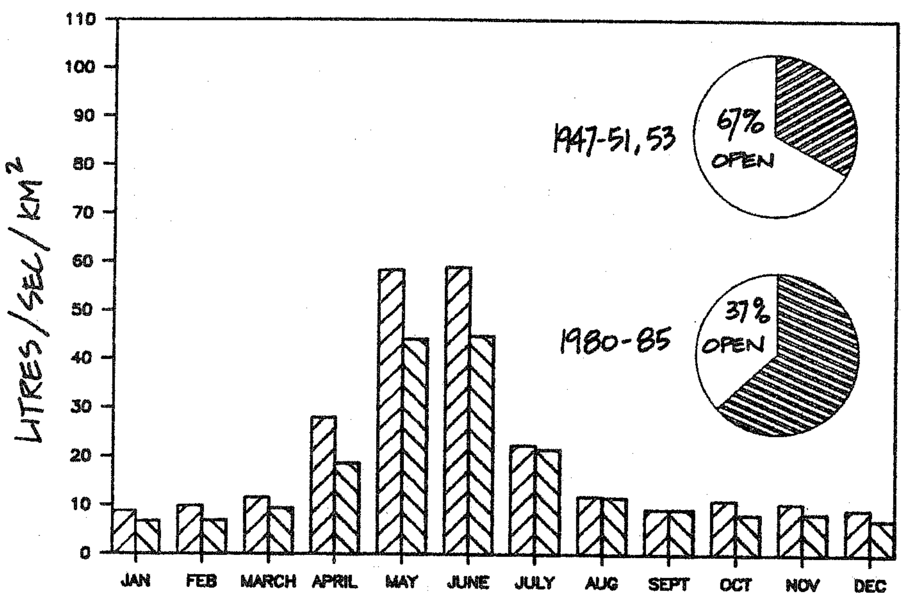

Figure 2. A comparison of average monthly flows for the years 1947-51, 53 and the years 1980-85. The pie graphs indicate percent of the watershed with a closed and open canopy.

Thirdly, we suggest that forest hydrology research emphasize risk analysis rather than average water yield change. If we are concerned about erosional impacts of flow changes we are concerned about extreme events rather than average annual or monthly flow changes. Studies of rain-on-snow in coastal climates (Harr and Berris 1983; Beaudry and Golding 1985) have emphasized the processes during individual climatic events with a view to making inferences on how localized changes due to forest canopy removal might affect a stream hydrograph during an extreme event. Similar analysis of significant runoff events are necessary in the interior to get a better understanding of key events that are important in changing channels and carrying most of the sediment load. We are initiating such research in southeastern B.C. and have installed lysimeters and associated climatic instrumentation to compare melt rates in an adjacent forested and clearcut site. Lysimeter and hydrograph data from the 1987 peak flow event are shown in figure 3. It can be seen that peak annual melt rate is considerably higher in the clearcut site yet the snowmelt contribution from the forested site contributes during the crucial peak flow period when snow has already disappeared in the clearcut. On this site forest cover removal had a desynchronizing impact. This peak flow event was the result of an unusual hot spell at the end of April that culminated with an intense precipitation event on May 1. Although the peak maximum flow was not particularly high, it triggered several debris avalanches in nearby areas. The key question is how harvesting will change the response of slopes and channels to important events such as illustrated in this example.

A fourth requirement is for better differentiation of important geographical areas from a snow management viewpoint. An important start in differentiating zones has been undertaken by Troendle and Leaf (1980) in the WRENSS document, however, more work must be done to differentiate areas where warm wet snowpacks predominate from those where continental cold snowpacks are important and snow redistribution is considered to be a more important process.

CONCLUSION

There are significant gaps between the principles that have been demonstrated in the scientific literature and what the practitioner must infer to do his job. The principles that have been demonstrated on plot studies and small watershed studies have not been demonstrated on larger watersheds that are the typical management units with which managers are confronted. A researcher may argue that a larger watershed is simply too complex to carry out properly controlled studies. In many cases it may be impractical or excessively expensive yet it is necessary if we are to ultimately apply snowpack management principles on a watershed scale.

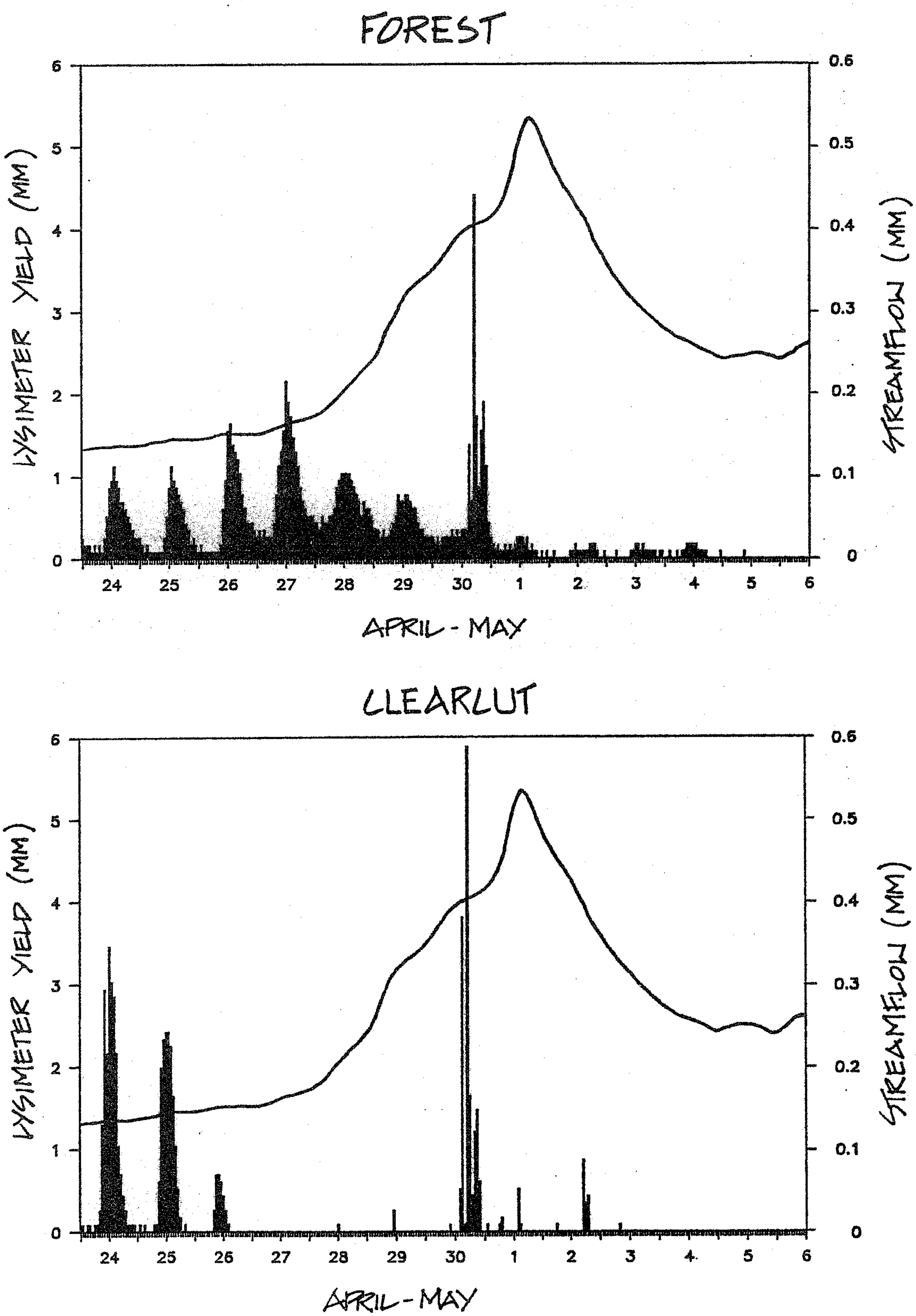

Figure 3. Graphs illustrating snowmelt from an adjacent forested and clearcut site during the 1987 peak runoff as well as streamflow of a nearby stream.

REFERENCES CITED

Anderson, H. W. 1956. Forest cover effects on snow pack accumulation and melt, Central Sierra Snow Laboratory. Trans. Amer. Geophys. Union 37:307-312.

B.C. Ministry of Environment. 1980. Guidelines for watershed management of Crown lands used as community water supplies. Interministry Task Force. Victoria, B.C.

Beaudry, P. G. and D. L. Golding. 1985. Snowmelt and runoff during rain-on-snow in forest and adjacent clearcut. In Snow Property Measurements Workshop. Lake Louise, Alberta. Tech. Memo. 140. National Research Council of Canada. Ottawa. pp. 285-311.

Bosch, J. M. and J. D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J. Hydrol. 55(3):3-23.

Golding, D. L. and R. H. Swanson. 1986. Snow distribution patterns in clearing and adjacent forest. Water Resources Research 22:1931-1940.

Harr, R. D. 1981. Scheduling timber harvest to protect watershed values. In Interior West Watershed Management Symposium. D. M. Baumgartner (editor), Washington State University, Pullman, Wash. pp. 269-280.

Harr, R. D. 1986. Myths and misconceptions about forest hydrologic systems and cumulative effects. In Calif. Watershed Management Conf. Wildland Resources Center Report No. 11. pp. 137-144. University of California, Berkeley, Calif.

Harr, R. D. and S. N. Berris. 1983. Snow accumulation and subsequent melt during rainfall in forested and clearcut plots in western Oregon. In Proc. 51st Western Snow Conference, Vancouver, Washington. pp. 38-45.

Haupt, H. F. 1951. Snow accumulation and retention on Ponderosa pine lands in Idaho. J. Forestry 49:869-871.

Haupt, H. F. 1979. Local climatic and hydrologic consequences of creating openings in climax timber in North Idaho. U.S.D.A. For. Ser. Res. Pap. INT-223.

Hetherington, E. D. 1987. The importance of forests in the hydrologic regime. In Canadian Aquatic Resources. M. C. Healey and R. R. Wallace (editors). Canadian Bulletin of Fisheries and Aquatic Sciences 215. Dept. of Fisheries and Oceans. Ottawa. pp. 179-211.

MacDonald, L. H. 1987. Forest harvest, snowmelt and streamflow in the central Sierra Nevada. In Forest Hydrology and Watershed Management. Proc. Vancouver Symp. Aug. 1987. IAHS-AISH Publ. No. 167. pp. 273-283.

Packer, P. E. 1962. Elevation, aspect, and forest cover effects on maximum snowpack water content in a western white pine forest. Forest Sci. 8:225-235.

Packer, P. E. 1971. Terrain and cover effects on snowmelt in a western white pine forest. Forest Sci. 17:125-134.

Satterlund, D. R. and H. F. Haupt. 1972. Vegetation management to control snow accumulation and melt in the Northern Rocky Mountains. In National Symposium on Watersheds in Transition. Colorado State University. pp. 200-205.

Swanson, R. H., and G. R. Hillman. 1977. Predicted increased water yield after clear-cutting verified in west-central Alberta. Can. Dept. Fish. Environ., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-198.

Swanson, R. H., D. L. Golding, R. L. Rothwell, and P. Y. Bernier. 1986. Hydrologic effects of clear-cutting at Marmot Creek and Streeter Watersheds, Alberta. Can. For. Serv., North. For. Res. Cent. Inf. Rep. NOR-X-278.

Toews, D. A. A. and D. R. Gluns. 1986. Snow accumulation and ablation on adjacent forested and clearcut sites in southeastern British Columbia. In Proc. 54th Western Snow Conference. Phoenix, Az. pp. 101-111.

Troendle, C. A. 1983. The potential for water yield augmentation from forest management in the Rocky Mountain region. Water Resour. Bull. 19(3):359-373.

Troendle, C. A. and C. F. Leaf. 1980. Hydrology, Chapter III. In An approach to water resources evaluation of nonpoint silvicultural sources. EPA 60018-80-012. Environmental Reseach Laboratory, Athens, Ga.

Troendle, C. A. and C. F. Leaf. 1981. Effects of timber harvest in the snow zone on volume and timing of water yield. In Interior West Watershed Management Symposium. D. M. Baumgartner (editor), Washington State University, Pullman, Wash. pp. 231-243.

U.S.D.A. Forest Service. n.d. Forest hydrology, Part II, Hydrologic effects of vegetation manipulation. U.S.D.A. For. Serv., Missoula, Mont.